

# The “Depth” of Depth of Field Is a Convention, Not a Measurement

— With the same 50 mm lens at the same  $f/2.8$ , the hyperfocal distance is **29.8119** m and also **207.6912** m —

What changed is not the equipment but the circle of confusion, which is an agreement — One set of equipment holds four answers — [Paper 358]

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— *From thinking to syncing.* —

## Abstract

Depth of field is printed in tables and looks like a property of the lens. This paper asks where that number comes from—the answer is that it comes not from the equipment but from an agreement about when blur becomes visible. No new mathematical theorem and no new law is claimed. First, the formula contains the circle of confusion  $c$ , and  $c$  is not a measured value (Section 2). Second, this is the core of the paper. At the same 50 mm and  $f/2.8$ , changing  $c$  from 0.0300 to 0.0043 mm takes the hyperfocal distance from 29.8119 m to **207.6912** m, a factor of **6.9667** (Section 3). Third, not one thing about the equipment has changed (Section 3). Fourth, stopping down to  $f/8$  does not remove the four answers; they line up from 10.4667 to **72.7244** m (Section 3). Fifth, the traditional  $c = 0.030$  mm at  $f/8$  gives 10.4667 m, matching the accepted “about 10 m” (Section 4). Sixth, the separator is  $c$ , not the lens and not the aperture (Section 5).

Scope of this paper (scope note): No new mathematical theorem and no new law is claimed—the circle of confusion, hyperfocal distance, and the depth-of-field formulae are all standard. We do not build optics—the theory of the diffraction limit, aberrations, and the point spread function is not entered. It is named and no more. Vision is not treated—the limits of human acuity and the psychophysics of viewing distance are not entered. Four provenances for  $c$  are simply set side by side. We evaluate no equipment—the performance of particular lenses and cameras is not the subject. We give no photographic advice—which  $c$  one ought to choose is not addressed. Diffraction is not included—the diffraction blur of a small aperture is not in the numbers. The computation is within the geometric-optics approximation. Relation to earlier papers: Paper 352 showed a transition temperature moving with the measurement's time scale—there what moved was the observation time; here it is an agreement about the limit of what can be told apart. Paper 355 showed restitution not to be a material constant—there the condition was impact speed. Paper 354 showed length ceasing to be the quantity that measures a curve—there too the choice of ruler fixed the answer. Paper 300 showed whether two things share a root is decidable—by that test, focal length and circle of confusion have distinct roots: the first is measured, the second is decided. What is added is setting four provenances for  $c$  side by side with the resulting hyperfocal distances, showing the answers spreading by a factor of 6.9667 on identical equipment, showing that changing the aperture does not remove the four, confirming the formula by matching the traditional value against the accepted figure, and putting the separator on  $c$ .

## 1. Notation and the Question

Setting: For focal length  $f$ , f-number  $N$ , and circle of confusion  $c$ , compute the hyperfocal distance  $H$  as

$$H = \frac{f^2}{Nc} + f$$

Take  $f = 50$  mm. Focused at  $H$ , everything from  $H/2$  to infinity falls within the depth of field.

### Observation 1.1

$f$  and  $N$  are fixed by the equipment. They are engraved on the lens—they can be measured, and anyone measuring gets the same value.

### Observation 1.2

$c$  is not like that. It is the limit at which blur becomes recognisable as blur—where that happens depends on the size viewed, the distance viewed from, and who is viewing.

### Observation 1.3

So  $c$  is an agreement. Not a property of the equipment but a stipulation about viewing conditions—and it sits in the denominator of the formula.

Question: Is a depth-of-field number a property of the equipment?

## 2. $c$ Has More Than One Provenance

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### Observation 2.1

$c = 0.030$  mm is the traditional 35 mm value. It corresponds to the 43.2666 mm diagonal divided by 1442—it comes from the condition of a print enlarged and held in the hand.

### Observation 2.2

$c = 0.020$  mm is a stricter criterion. Used when enlarging further—the same equipment, a different viewing condition, a changed agreement.

### Observation 2.3

$c = 0.015$  mm is used for high-pixel-count cameras. It assumes magnified viewing on a screen—an example of a habit — “viewing at 100 per cent” — changing the agreement.

### Observation 2.4

$c = 0.0043$  mm is the pixel pitch. It corresponds to one pixel of a 35 mm sensor of about 47 megapixels (computed: 46.7)—this one comes from the equipment, but it embeds the judgement that blur smaller than a pixel is meaningless.

### Observation 2.5

All four have grounds. None of them is wrong——so there is no external standard fixing “the correct  $c$ ”.

## 3. One Set of Equipment, Four Answers

Calculation 3.1: Hyperfocal distance against  $c$  (computed in this paper,  $f = 50$  mm).

| $c$ [mm] | Provenance                | $H$ at $f/2.8$ [m] | $H$ at $f/8$ [m] |
|----------|---------------------------|--------------------|------------------|
| 0.0300   | traditional 35 mm value   | 29.8119            | 10.4667          |
| 0.0200   | stricter criterion        | 44.6929            | 15.6750          |
| 0.0150   | high-pixel-count value    | 59.5738            | 20.8833          |
| 0.0043   | pixel pitch (about 47 MP) | 207.6912           | 72.7244          |

### Observation 3.2

This is the core of the paper. With the same lens at the same aperture, the answers spread from 29.8119 m to 207.6912 m——a factor of **6.9667**, and not one thing about the equipment has changed.

### Observation 3.3

The spread nearly equals the ratio of  $c$ . The  $c$  ratio is  $0.0300/0.0043 = 6.9767$  and the  $H$  ratio is 6.9667——because  $H$  is nearly proportional to  $1/c$ . The difference comes from the  $+f$  term.

### Observation 3.4

Stopping down does not remove the four. At  $f/8$  they become 10.4667 to 72.7244 m——everything simply shortens and the spread ratio is unchanged. The aperture is no substitute for the agreement.

#### Observation 3.5

The practical consequence is large. In landscape work, “where do I focus” answered as 29.8 m or as 207.7 m is a different way of shooting—one set of equipment at one setting has two correct answers.

### 4. The Formula Itself Is Right

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#### Observation 4.1

The traditional value matches the accepted figure.  $c = 0.030$  mm, 50 mm, f/8 gives  $H = 10.4667$  m—agreeing with the accepted “about 10 m”. Formula and arithmetic are both right.

#### Observation 4.2

The direction is right too. A smaller  $c$  lengthens  $H$ —matching the intuition that a stricter criterion gives shallower depth.

#### Observation 4.3

So is the effect of the aperture. From f/2.8 to f/8,  $H$  goes from 29.8119 to 10.4667 m—a ratio of 2.8483, just short of the f-number ratio  $8/2.8 = 2.8571$  because of the  $+f$  term.

#### Observation 4.4

So the trouble is not the formula. It answers correctly for whatever  $c$  it is given—the trouble is that  $c$  arrives from outside the formula.

#### Observation 4.5

To be stated honestly—this paper does not say depth of field is meaningless. State  $c$  and the number is completely determined—what is said is that one must not report a depth number without reporting  $c$ .

## 5. The Separator: $c$

### Observation 5.1

The separator——the circle of confusion; not the lens and not the aperture.

| Quantity                | Provenance   | Measurable | Effect on $H$ |
|-------------------------|--------------|------------|---------------|
| Focal length $f$        | the lens     | yes        | as the square |
| f-number $N$            | the lens     | yes        | inversely     |
| Circle of confusion $c$ | an agreement | no         | inversely     |

### Observation 5.2

Only the third row differs in character. Its effect on  $H$  is the same inverse dependence as  $N$ , but its provenance is different——inside the formula they look alike; outside it they are not.

### Observation 5.3

Distinct roots by the criterion of Paper 300. Entering the formula in the same shape does not make two quantities the same kind——one is a measurement, the other a convention.

### Observation 5.4

The separator can be moved. Fix a rule computing  $c$  from viewing conditions (frame diagonal, viewing distance, acuity) and  $c$  moves toward being a measured quantity——but the agreement about what acuity to assume remains. An agreement changes place; it does not vanish.

### Observation 5.5

To be stated honestly—207.6912 m and the factor 6.9667 follow from four values of  $c$  chosen and stated explicitly. Another four give other numbers—what does not move is only that  $H$  goes inversely with  $c$  and that  $c$  arrives from outside the formula.

### Observation 5.6

One last thing—if even one agreement sits inside a formula, the number coming out is a function of that agreement. Depth of field looks as though it is set by  $f$  and  $N$ , and is in fact set by  $c$ —unless one keeps track of which quantities are measured and which are stipulated, a stipulation gets mistaken for a measurement.

## 6. The Census and the Close

1.  $H = f^2/(Nc) + f$  (Section 1):  $c$  is in the denominator.
2.  $f$  and  $N$  are measurable (Observation 1.1): engraved on the lens.
3.  $c$  is not (Observation 1.2): an agreement about viewing.
4. At  $f/2.8$ , 29.8119 m to 207.6912 m (Calculation 3.1): four answers, one camera.
5. A spread of 6.9667 (Observation 3.2): near the  $c$  ratio 6.9767.
6. At  $f/8$ , 10.4667 to 72.7244 m (Calculation 3.1): stopping down does not remove it.
7.  $c = 0.030$  at  $f/8$  gives 10.4667 m (Observation 4.1): matches the accepted figure.
8. Aperture ratio 2.8483 (Observation 4.3): just short of  $8/2.8 = 2.8571$ .
9. The formula is right (Observation 4.4): the trouble is that  $c$  comes from outside.
10. An agreement changes place (Observation 5.4): the acuity convention remains.

Closing: Depth of field is printed in tables and looks like a property of the lens—but the number is not fixed by the equipment alone. The denominator of  $H = f^2/(Nc) + f$  holds the circle of confusion  $c$ — $f$  and  $N$  are engraved on the lens and anyone measuring gets the same value, while  $c$  is the limit at which blur becomes recognisable as blur, and where that happens depends on the size viewed, the distance viewed from, and who is viewing. So  $c$  is not a property of the equipment but a stipulation about viewing conditions. And there is more than one stipulation—the traditional 35 mm 0.030 mm, the stricter 0.020 mm, the high-pixel-count 0.015 mm, and the pixel pitch 0.0043 mm. All four have grounds and none of them is wrong. So one set of equipment holds four answers—at  $f = 50$  mm and

f/2.8 the hyperfocal distance is **29.8119 m**, **44.6929 m**, **59.5738 m**, and **207.6912 m**. A spread of **6.9667**, with not one thing about the equipment changed. Stopping down to f/8 simply shortens them all, to 10.4667 through 72.7244 m, leaving the spread ratio unchanged: the aperture is no substitute for the agreement. In landscape work, “where do I focus” answered as 29.8 m or as 207.7 m is a different way of shooting. The formula itself is right—the traditional  $c = 0.030$  mm at f/8 gives  $H = 10.4667$  m, agreeing with the accepted “about 10 m”. A smaller  $c$  lengthens  $H$ , and the f/2.8-to-f/8 ratio 2.8483 falls just short of the f-number ratio  $8/2.8 = 2.8571$  because of the  $+f$  term. The trouble is not the formula but that  $c$  arrives from outside it. One thing separates them—the circle of confusion; not the lens and not the aperture.  $c$  acts on  $H$  with the same inverse dependence as  $N$ , so inside the formula they look alike — but one is a measurement and the other a convention. Fix a rule computing  $c$  from viewing conditions and it moves toward being measured, yet the agreement about what acuity to assume remains: an agreement changes place, it does not vanish. To be said honestly—this paper does not say depth of field is meaningless. State  $c$  and the number is completely determined. What is said is that one must not report a depth number without reporting  $c$ . One last thing—if even one agreement sits inside a formula, the number coming out is a function of that agreement. Depth of field looks as though it is set by  $f$  and  $N$ , and is in fact set by  $c$ . Unless one keeps track of which quantities are measured and which are stipulated, a stipulation gets mistaken for a measurement.

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